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ABSTRACT

Discoveries, background information, and facts concerning atomic structures and atomic energy are detailed in this booklet. The discussion considers time, space, and spirit. Time refers to a sense of history; space refers to geography; and spirit refers to life and thought. Several chapters regarding the concept of the atom, a time line of the concept, a map of important geography related to the concept, a glossary of important terms, and a list of several study suggestions are included. (CW)

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The Atom

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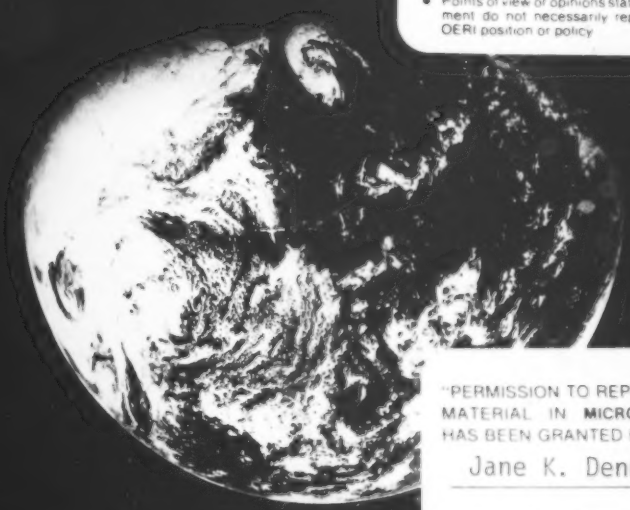

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A HAWKHILL LEARNING POWER BOOK

2

TIME, SPACE AND SPIRIT

KEYS TO SCIENTIFIC LITERACY

To the student,

This short book will help you understand our modern world. It has changed a lot since your parents were born. Even more since you were born. And it will change still more–much more–in your lifetime.

What is behind most of these big changes? Two things. Science and technology.

What can you do about it? The first step is to understand more about science and technology and how they connect with our world. Especially the ever-growing world of free democratic societies. One way to do this–the way this book follows–is to look at the world from three angles: *Time, Space* and *Spirit.*

Time means history. You can learn how science and technology have worked in the past and are working today.

Space means geography. You can learn where important things happened in the past and are happening today.

Spirit means life. The life of the mind. You can learn the key words, concepts and ideas that power science and technology (and society) today.

This book teaches about science, technology and society from all three of these angles–*Time, Space* and *Spirit.*

Read on.

This book belongs to:

The Atom

Bill Stonebarger
Illustrations by Lin Haley

Hawkhill Associates
Madison, Wisconsin

This book is one of a series of sixteen Learning Power Books in the *Time, Space and Spirit–Keys to Scientific Literacy* series. It is designed to accompany the video program of the same name.

The *Time, Space and Spirit–Keys to Scientific Literacy* series was written and produced with consultation from the History of Science Department at the University of Wisconsin-Madison.

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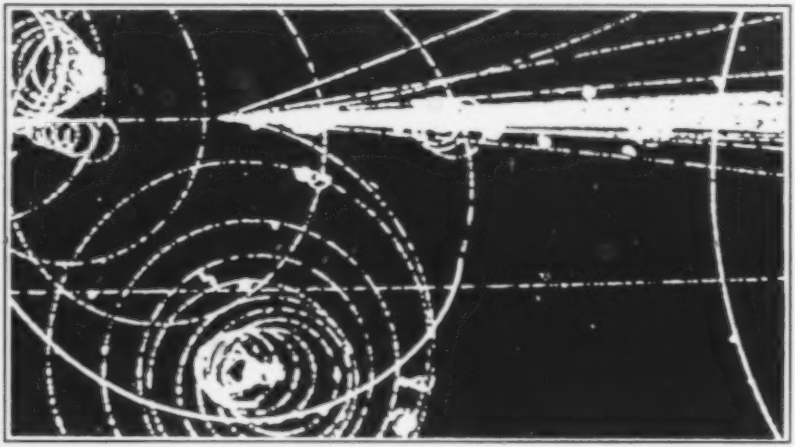
Part 1: How We Found Out about Atoms



the "useless electron"

"To the useless electron, long may it be so!" So went a turn-of-the-century dinner toast at the Cavendish Laboratory, in Cambridge, England–where the electron was first discovered.

"Moonshine! Pure moonshine!!" That's what Ernest Rutherford, one of the pioneers in the study of the atom, said about atomic power.

Seldom have so many been so wrong. And seldom have so few been so important.

This is the story of human beings and the atom.

2500 years ago

It all began, as so much in science did, about two thousand five hundred years ago, in ancient Greece. Here the world's first scientists lived and wondered and asked the big questions. Questions like "What is the world made of?"

One of these scientists, a man named Democritus,

would sit in the central market place of Athens and explain to one and all how all things on earth and in the heavens are made of extremely tiny particles. He gave them the name "atoms."

Democritus invents "atoms"

These atoms combine and uncombine, arrange and rearrange themselves into air, earth, fire and water. Into trees and stones, into ships and sails, into frogs and human beings. The trees and frogs and human beings live and die. The atoms are eternal. Thus, claimed Democritus, the atoms that now live in my brain once lived in the brain of Homer and will live in the brains of all the scientists to follow us down the corridors of time.

little evidence

It was a pretty theory, but not many believed him. Perhaps they thought he was joking, for Democritus was called the "laughing philosopher." And Democritus had little evidence. But then neither did anyone else for their own theories about the world and the stuff it was made of. It would be well over two thousand years before such evidence was to come into the world.

key concept for scientific literacy

When it did, it would make the concept of the atom one of the most important and most powerful of all scientific ideas. And it would make an understanding of this concept one of the keys to scientific literacy in our own late twentieth century.

The first really big steps forward after Democritus were taken about the time of our American Revolution. Three men–each one strikingly different–played crucial roles.

the minister who invented soda pop

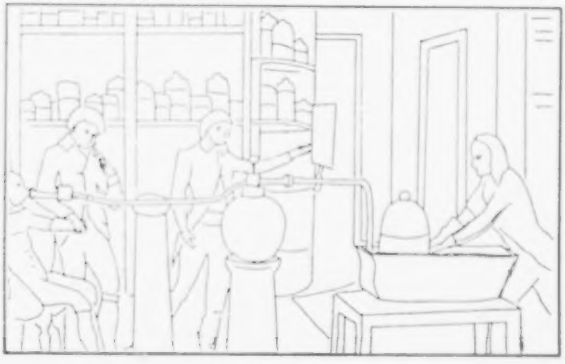
One is now honored by a statue in his home town in England–the same town that once bred a mob that burned down his house to protest his democratic political views. He was a Unitarian minister and a friend of Benjamin Franklin. He discovered the element oxygen, made the first artificial gas and the first bottle of soda pop. His name was Joseph Priestley.

the misogynist who weighed the world

The second was an eccentric English millionaire who hated money, polite society and women as much as he loved working alone in his London townhouse. Here he discovered a new gas, hydrogen. Here he was the first to figure out that water was a compound of hydrogen and oxygen. And here he was the first man to actually weigh the earth! His name was Henry Cavendish.

the aristocrat who solved the mystery of fire

The third pioneer was an aristocratic Frenchman who gets credit for solving the ancient mystery of fire. For replacing the outdated, phlogiston theory of fire with the modern oxidation theory. All this and more before losing his head to the guillotine



in the French Revolution. "The Republic has no need of philosophers," said the new president of France, as he sent Antoine Lavoisier to his death.

Priestley, Cavendish and Lavoisier were at their best in the experimental laboratory, puzzling their way through a mass of often irrelevant data to discover new chemical facts.

the school teacher who put it all together

The man who wove those patterns of fact into a tapestry of rich and effective theory was just the opposite–clumsy and slipshod in the laboratory but brilliant in the study. His first study was at a small Quaker school in Kendal, on the border of the beautiful lake country of northwestern England. The man was a poor English schoolmaster named John Dalton.

the first modern atomic theory

As was the custom in those days, Dalton advertised for pupils, and was paid per subject taught. Only a teenager himself, a poor speaker, and colorblind to boot, Dalton had his hands full at Kendal. Nevertheless, in between teaching and trying to discipline students often as old as he was, Dalton taught himself chemistry and began to fashion the key that would unlock a treasure chest of richness and power over the next two centuries. That key was the first modern atomic theory.

Dalton had evidence

Dalton's idea of the atom was similar to that of Democritus, but there was one enormous difference. Dalton had solid experimental evidence to back it up.

simple whole-number ratios

Dalton, for instance, knew that when chemical elements like carbon and oxygen combine to make carbon monoxide in one case, and carbon dioxide in another, they always do so in simple whole-number ratios. One part oxygen by weight, that is, combines with a given amount of

carbon to make carbon monoxide. To get carbon dioxide you have to exactly double the amount of oxygen.

law of definite proportions

So too with every chemical compound then known, the elements that make it up always combine in definite proportions. And if the same elements form more than one compound, the proportions are always simple whole-number ratios.

Why? Dalton asked.

explained by hypothesis of Dalton

The explanation, he answered, is simple. Every element must be made of atoms. Atoms, he imagined, looked like round "billiard balls." He himself made some models, now on view at the Museum of Science in London.

Each element is itself made of one particular kind of atom, Dalton guessed. Thus when oxygen combines with carbon it must do so all or none. One atom, two atoms, three atoms bond to one atom, two atoms, three atoms (or whatever) of the other element.

no direct evidence yet

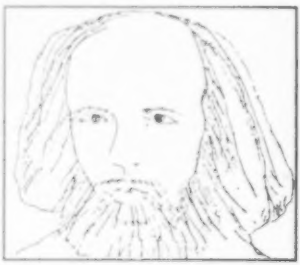
This hypothesis of Dalton proved to be one of the most fertile in all scientific history. No one yet, it is true, had any direct evidence for these tiny

atoms. No one had actually "seen" them. But after Dalton the indirect evidence (and the usefulness) of atomic theory quickly became overwhelming.

"Brownian Movement" and more

Some examples. Boyle's law–that the product of the pressure and volume in a gas was a constant; Avogadro's hypothesis–that equal volumes of gases contain equal numbers of molecules; and the erratic careening of spores under a microscope first noticed by Robert Brown and later called "Brownian movement"–all these and more were simply and elegantly explained by assuming all matter is made of atoms. And even more important, by so assuming, one knew where to look for still more important game.

the Russian card player



By the middle of the nineteenth century, as more elements were being discovered (and hence more different kinds of atoms), along came a bearded Russian, Dmitri Mendeleev, who liked to play cards. Mendeleev would write the names of all the elements then known on cards, along with their properties, including their atomic weights. Then he would sort these cards in as many ways as he could think of, searching for a pattern.

Here is a pattern he found. The periodic table of the elements. When Mendeleev first made it up, it wasn't complete. Only 63 elements had been discovered by then, 63 different kinds of atoms. When he arranged his 63 cards in rows and columns, he noticed that when the rows were seven across, the columns down always had elements with much in common. But occasionally there was a gap.

bold guesses

"There is an element as yet undiscovered," proclaimed Mendeleev with great chutzpah. "I have named it eka-aluminum. By properties similar to those of the metal aluminum you shall identify it. Seek, and it will be found."

he was right

And by golly, he was right. It was found! Since it was found in France, it was named gallium. Mendeleev predicted two other elements and they too were found just as he said they would be.

all wrapped up?

By the end of the nineteenth century the periodic table had grown a lot. Atomic theory was proving clear and useful. Some not-so-imaginative scientists thought we had everything all wrapped up.

they were wrong

They were dead wrong. New facts about the atom around the turn of the century were to bring a new revolution in both science and society, a revolution we today are still struggling to understand and to control.

discovery of x rays

The first shot in this revolution was fired in 1895 by William Roentgen in Germany. Roentgen was experimenting with high voltage tubes at the University of Wurzburg in Bavaria when he discovered some strange invisible rays that came out of his tubes. These rays, he found, easily penetrated the skin of people, giving a picture of their bones! He called these mysterious unknown rays–"x rays."

Almost as soon as he published his findings, he and his x rays became world famous. The New Jersey legislature tried to pass a law banning x rays from use in opera glasses–in order to protect the modesty of ladies.

The big question for science was–where are these unknown rays coming from? What are they?

Becquerel discovers radioactivity

Within months another startling discovery was made in Paris. Henri Becquerel found that a plain chunk of uranium would darken photographic plates. Something, in other words–we know not what–seemed to be coming out of the uranium atoms!

the Curies find radium

Marie and Pierre Curie at the University of Paris were working in their garage and finding still more rays and penetrating particles that came out of an element they discovered and called radium. What was happening to the uranium and the radium atoms that caused them to emit these powerful particles and rays? And most amazing of all, to change themselves into smaller, simpler atoms in the process!

For yes, Marie Curie and others were finding that the medieval alchemists were right! One element could be changed into another!

a strange "light"

William Crookes, in England, drew air out of a glass tube, then put a high voltage across the tube. He saw a ghostly column of light. But was it light? When he put a magnet near it, the spooky column of "light" bent!

Thomson calls it "electrons"

J. J. Thomson at the Cavendish Laboratory in Cambridge, England, was the first to recognize the glow in Crooke's tubes must be caused by a fast-moving stream of what he called "electrons." And even more important, these "electrons" must

be coming right straight out of the very atoms themselves! The billiard balls that Dalton had imagined seemed to be spitting out seeds!

protons discovered

Soon Cavendish Lab and other centers were finding that besides the negatively charged electrons, the atom has positively charged particles as well. These were later called "protons." But then the question arose, how were protons and electrons put together in the normal neutral atom?

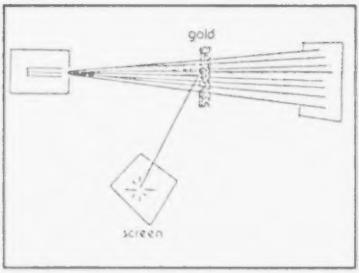
Ernest Rutherford solves a puzzle

The most important single breakthrough in sketching out a picture of the inner structure of the atom came at the University of Manchester in England, in the lab of a rough young New Zealander, Ernest Rutherford.

Though it was known that atoms were made of electrons and protons now, no one knew how they were stuck together. Was the atom a sort of plum pudding? If not that, what?

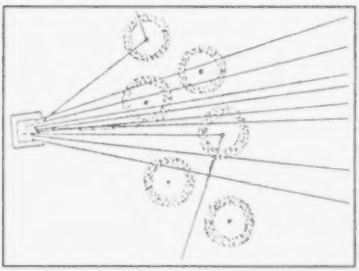
experimental breakthroughs

One day one of Rutherford's assistants came rushing into his office to show him some remarkable data from a new experiment. In a vacuum chamber Rutherford had been bombarding thin sheets of metal foil with fast-moving alpha particles (positively charged particles of the same size as a small atom itself). If the atom was a kind of plum pudding of protons and electrons, as Thomson had proposed, the



alpha particles should pass through mostly undeflected. But that is not what happened.

Most of the alpha bullets did pass through undeflected, but a few, a very few, bounced back as though they had hit a brick wall!



"It was quite the most incredible event that has ever happened to me in my life," Rutherford said later. "It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you!"

new view of the atom

In a very short time Rutherford took the data into his study and sketched out a new picture of what an atom might look like. He imagined the atom to be like a miniature solar system. A very small, positively charged nucleus was surrounded by a swarm of light high-speed electrons. The actual dimensions of this "solar system," as proven by his experiments, were staggering to say the least.

a "period" in a "classroom"

If the nucleus, he calculated, was magnified as big as a period on a piece of paper, the electrons would be buzzing around in a space as large as a big classroom! And that is why the alpha particles mostly passed through undeflected (the space in a classroom), but very occassionally hit a brick wall (the period).

surprises only beginning

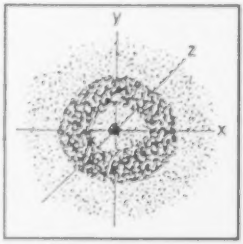
The surprises were only beginning now. During the next fifty years physicists and chemists would change the world with the power of their ideas. As they would astound the philosophers with the wonder of the new mysteries.

Niels Bohr and spectral lines

Niels Bohr from Denmark studied the fingerprints of the atoms–the colored spectral lines emitted by glowing elements. He guessed that these lines, so definite and so pure, came from definite–he called them quantum-leaps within the electronic structure of the individual atoms of any element. Working with this guess he constructed still another, more sophisticated, picture of what the inside of an atom might look like.

electron as "wave particle"

Bohr's picture of the atom was in turn replaced by a still more sophisticated one where the electrons became wave-particles surrounding the nucleus in clouds of probability. The clouds of probability were not vague dreams, however. They were mathematically precise. Physicists could use them to predict atomic behavior. Chemists could use them as an aid in thousands of chemical bond studies to come. It is hardly too much to claim that most of modern chemistry (and a great deal of modern molecular biology) is built on the foundation laid by these pioneers of basic physics.



the mysterious nucleus

The electron clouds of the atom were one thing. The hard nucleus core was another. It too was probed deeper and like a series of Chinese boxes within boxes within boxes, it began to reveal itself in all its mystery and power.

neutron is discovered

In the middle of the depression, with Hitler coming to power in Europe, a scientist in Cavendish Laboratory, James Chadwick, found that besides protons and electrons, there was a third particle in the atom–the neutron. And the

neutron was somehow stuck in that hard nucleus core.

isotopes

It was noticed, too, that all atoms of a given element were not exactly alike. Each element had atoms that always had the same number of electrons and protons, but differing numbers of neutrons. And some of these "isotopes" of an element–as they came to be called–were unstable. This helped explain why the radium and uranium that Marie Curie and others had worked with, broke apart in an unpredictable and highly energetic way. Highly energetic indeed. Conforming exactly to Einstein's new equation, $E=mc^2$.

Rutherford was wrong

Scientists probing the atom began to wonder whether Rutherford was right when he labelled the idea of atomic power "moonshine." There seemed to be vastly more power there than anyone had ever before dreamed. Two tracks of science, the wonder and the power, converged to unlock the secrets of that atomic nucleus. As Hitler and Stalin came along in the 1930s, as the Second World War approached, the race to unlock those secrets turned desperate.

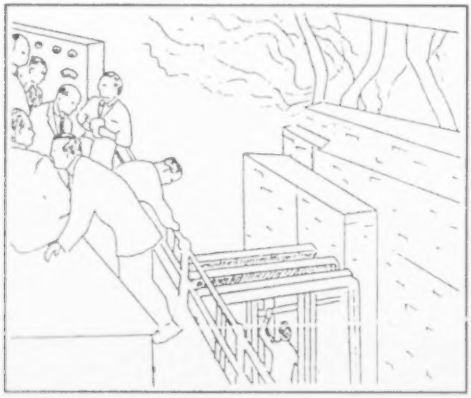
as war approaches

Many of the world's greatest scientists, men like Albert Einstein, Niels Bohr, Edward Teller, Enrico Fermi and others, fled Hitler's Germany and Mussolini's Italy, to continue their work in the free world of England and America. Some remained in Germany of their own free will, and some by compulsion, to work on atomic energy and its possible use in warfare.

the first nuclear pile at the University of Chicago

In the United States, Enrico Fermi led a team of nuclear physicists at the University of Chicago who constructed the first working nuclear pile. It was built in the squash courts under the football stadium.

Below you see a drawing taken from a famous painting showing the world's first demonstration of nuclear energy in a working nuclear reactor.



U-235 is separated

At Oak Ridge, Tennessee, a giant government-built factory began work on separating two isotopes of uranium, the normal U-238, from the rare U-235 (capable of fission).

At Alamogordo, New Mexico, July 16, 1945, 5:30 a.m., the first atomic explosion was detonated.

Hiroshima and Nagasaki

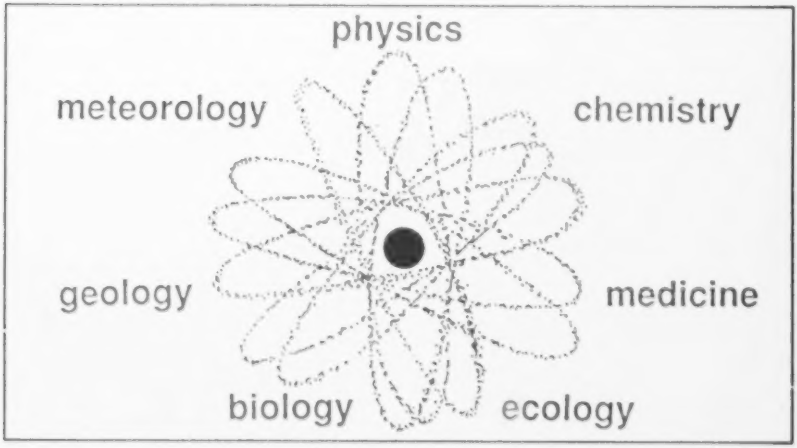
Less than a month later, the first atomic bombs were used in warfare. Hiroshima and Nagasaki, Japan, were devastated. The most destructive war in human history was ended.

No, the electron was not useless. No, atomic energy was not moonshine. And all over the world today, the power of the atom is leading scientists and citizens ever closer to utopia or to annihilation.

the mystery of mysteries

And the wonder of the atom is leading scientists and citizens ever closer to the mystery of mysteries–creation itself.

Part 2: What We Know about Atoms



a bedrock foundation

Few concepts in modern science have had as wide and as deep an impact as that of the atom. Physics, chemistry, biology, geology, meteorology, medicine, ecology, even psychology and anthropology count knowledge of the atom as basic data, part of the bedrock foundation upon which their science is built.

Here is what we know today.

all things are made of atoms

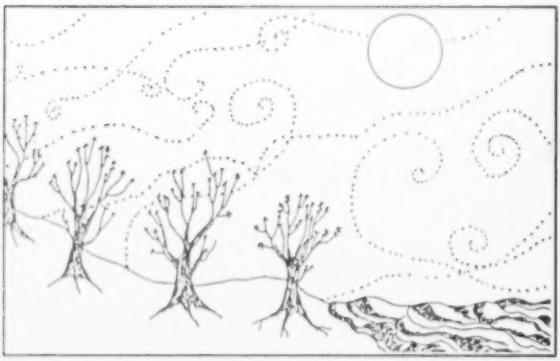
One. All things on earth (and in the universe) are made of atoms. All material things, that is. Trees and stones, birds and lakes, frogs and people. All things. No exceptions.

atoms are very small

Two. Atoms are very small. So small that in a single drop of sea water there are fifty billion atoms of gold. Yet you would have to distill two thousand tons of sea water to get enough gold to see with the naked eye.

atoms in motion

Three. Atoms (or combinations of atoms called molecules) are continually in motion, and that motion is what we call heat. Atoms that make up the balmy air of a summer day, for instance, are traveling at speeds three times greater than that of a bullet leaving the muzzle of a rifle.



absolute zero

And they collide with their neighboring atoms and molecules over five thousand million times a second. Only as you approach the coldest possible temperature in the universe–273 degrees below zero centigrade–do the atoms quiet down and come to rest. Even then they quiver inside for ...

inner structure of atoms

Four. Atoms, small as they are, have an inner structure as intricate and finely tuned as the most elegant watch. An atom is not a little billiard ball, nor is it a miniature solar system as formerly thought. It does have an incredibly small, incredibly dense nucleus, which is surrounded by clouds of electrons.

To give you some idea of proportion, if we were to enlarge a single atom to the size of Yankee Stadium, the tiny dense nucleus would be the size of a mosquito over second base.

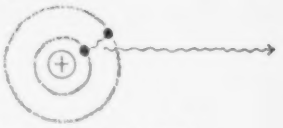
The atom's nucleus has positive electrical charges,

while the electrons around it have negative electrical charges. The differences between one kind of atom and another are due to differences in the number and arrangement of these electrical charges.

chemical changes

Five. All of the ordinary and extraordinary chemical changes in our world, from burning wood to digesting food, from making steel to thinking thoughts, are due to changes in the orbiting electrons, as bonds are made and broken between one atom and another.

electrons and radiation



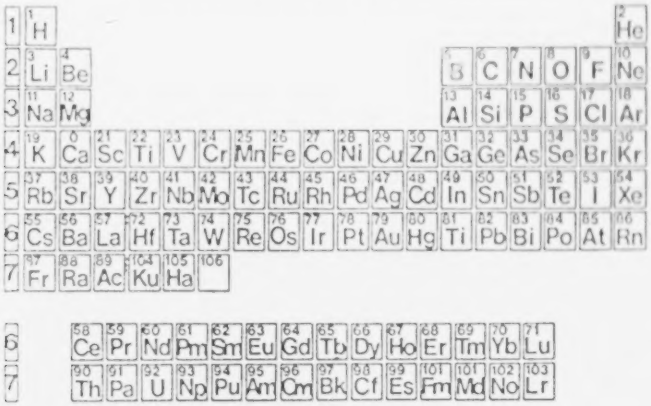
Six. Other kinds of changes in the movements of the atom's electrons produce radiation, including visible light and electricity!

nuclear changes

Seven. All the ordinary and extraordinary nuclear changes in our world, from atomic power plants to cancer radiation therapy, from atomic explosions to solar energy to are due to arrangements and rearrangements of the dense atomic nucleus.

periodic table of elements

That's a summary. Now let's see how these well-established facts help us understand our world.


1 H
2 He
2 Li Be B C N O F Ne
3 Na Mg Al Si P S Cl Ar
4 K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
5 Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
6 Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
7 Fr Ra Ac Ku Ha
6 Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
7 Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr

the master chart

Start with chemistry. Practically all chemical knowledge today has as its bedrock foundation, atomic theory. At the bottom of the opposite page you see a modern periodic table of the elements. This table, which you will find in all chemistry classrooms and chemical laboratories, is the master chart of all that exists in the material universe.

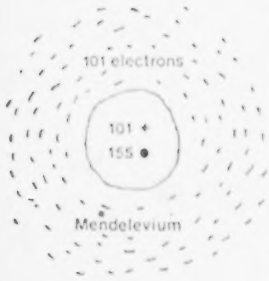
100-plus elements

It starts in the upper left-hand corner with the simplest of atoms, hydrogen, element number one. Hydrogen has just one unit of positive charge in its nucleus. Next comes helium, with two charges, followed by lithium with three, beryllium with four. We keep adding one charge each time right on through the entire 100-plus elements on the chart. No gaps nowadays. Everything is made of some combination of the 100-plus kinds of elements on this remarkable chart.

the universe in 100 flavors

Think what an extraordinary simplification this is! The universe itself in just over 100 flavors. Actually, only about 90 of these flavors seem to actually exist in nature at large. The others have been artificially created in our human laboratories.

artificial?

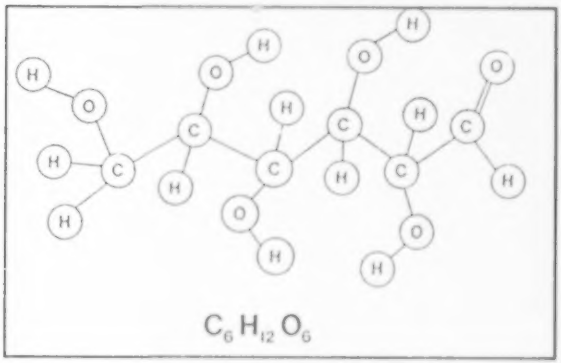


But wait! What does artificial mean? Mendelevium, for instance, has not yet been found in nature outside the laboratory, but the 101 protons, 155 neutrons, and 101 electrons that make up mendelevium are no different from the protons, neutrons, and electrons that make up the other elements. All elements, in other words, are made of the same parts. If mendelevium is ever found in nature outside the laboratory, we are quite confident it will be identical to the mendelevium we have made in our laboratory.

the atoms that make sugar

So, too, with other chemical substances. Sugar, for instance. On the next page is a model of sucrose,

the sugar in sugar cane, beet sugar and the bowl of sugar on your table. It is always made of

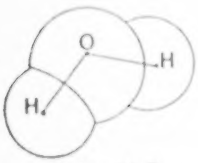


exactly the same kinds and numbers of atoms. Twelve atoms of carbon, twenty-two atoms of hydrogen, and eleven atoms of oxygen. Stuck together in the angles and geometry shown here.

"artificial" sugar?

Many green leaves know how to make this arrangement of atoms. Sugar cane leaves, corn leaves, maple leaves, peas, beans and all sprouts. We can also make this same arrangement of atoms in the laboratory, artificially. And there would be absolutely no difference between the natural and the artificial. Why should there be? We use the same atoms in making sugar that the corn leaf does. And for that matter, our laboratories are as natural (that is, made of the same elementai atoms) as the corn leaf.

chemical bonds



Water H_2O

More detailed and sophisticated knowledge of the electron shells surrounding each atom has led to more detailed and sophisticated predictions of how atoms will bond to one another. We know, for instance, not only that water is made of molecules of H_2O, but we know the angle at which the two hydrogen atoms are attached to the one oxygen atom. Knowing this angle enables us to predict correctly what water will do in an almost infinite

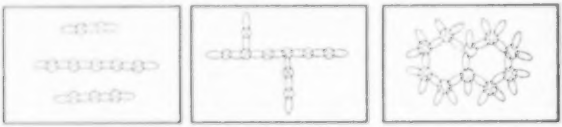
variety of physical and chemical reactions with other atoms and molecules.

carbon

So, too, with the most interesting of all atoms, carbon. It has six protons and six electrons. These electrons are positioned in their clouds such that a single carbon atom is able to make up to four separate bonds with other atoms. If it bonds with other carbon atoms in one way it makes superslippery graphite, the "lead" ... your lead pencil. If it bonds in another way it can make the hardest substance in the world–a diamond. And scientists at General Electric figured out how to make the bonds change–making graphite into diamonds!

carbon chains

But for carbon this is only the beginning. Carbon can hook up with itself in short or long chains, can branch, can turn into circles, can add other atoms to the corners and make an almost



unlimited number of substances from sugar to gasoline, from plastics to vitamins, from glue to hemoglobin.

DNA

Carbon can also make this–the crowning achievement of life–DNA (deoxyribonucleic acid)–a double helix of thousands of atoms strung along carbon-linked struts that contains on its spiralling structure the information needed to produce and control living things.

foundations of electronics

If modern chemistry is built on the bedrock of atomic theory, so too is modern electronics. In fact, chemistry, electronics and physics are all

becoming more and more interconnected as our web of atomic theory becomes ever more powerful.

the "useless electron?"

When the electron was first discovered in J. J. Thomson's Cavendish laboratory at the turn of the century, someone raised a toast "to the useless electron, long may it be so." If only they could visit a modern electronics store!

inventions and basic science

It is true that the telegraph, the telephone, radio and the phonograph were all invented before we knew there was such a thing as an electron. But now that we know more basic science, progress and invention have multiplied a hundredfold.

photovoltaic cells

Research on the behavior of atomic electrons in the presence of light, for instance, has led to modern photovoltaic cells which are able to generate electricity from sunlight using no movable parts.

fiber optics and silicon chips

The same direction of research has led to new glass fibers that are able to replace huge copper cables and carry messages around the world on the wings of light. And indeed, to the miracle silicon chips, the heart and soul of the modern computer.

the nucleus

The electron part of the atom is glamorous and popular. The nucleus, however, is haunted by fear and suspicion–yet now and then glowing with promise of a new world. For deep within the nucleus may well lie the ultimate secrets of creation. And as we probe into the atom's nucleus we find more and more puzzles. As the scientist J. B. S. Haldane once wrote, "the universe is not only queerer than we imagine, but it is queerer than we can imagine."

protons and neutrons ... quarks and antiquarks

Only a few years ago, we thought the nucleus was made up of protons and neutrons, held together by some kind of cosmic glue. In trying to figure out more about that "glue" we have run into more mysteries. The most accepted current idea is that protons and neutrons are themselves made of still smaller, simpler particles called quarks. These quarks come in at least four "flavors," as well as having opposite "antiquark" shadows.

power at Fermilab

In order to study the nucleus of an atom (ten million times smaller than the atom as a whole)–in order to intelligently search for these elusive quarks and antiquarks–humans have to use very powerful tools. One of the most powerful in operation today is the mile-long circular accelerator at Fermilab, in Batavia, Illinois. The forces we are dealing with in the atom's tiny nucleus are strong. So strong that Fermilab's giant "atom smasher" needs more electrical power than a city of 300,000 people to break them–and see what happens!

super-accelerator in Texas

The forces are so strong (and so important) that the United States Congress recently authorized the largest amount of money ever spent on a single scientific machine, a superaccelerator (still larger and more powerful than Fermilab) now being built in Texas.

cancer therapy

We know how to control these strong nuclear forces in nuclear chain reactions to generate electricity, or to explode in bombs. Many people do not know of the many other human uses of nuclear energy. Cancer, for instance, is being treated with growing success by the use of what are called radioisotopes.

radioisotopes

Radioisotopes are varieties of certain atoms whose nuclei spontaneously break apart. In that nuclear decay the atoms spit out energetic particles that can seek out and destroy fast-growing cancer cells.

radioactive isotopes in ecology and in genetics

Another use. Ecologists use tiny amounts of a radioactive isotope as a way of tracing the flow of chemicals through the environment. As a way of collecting basic data needed to understand and control pollution. In modern genetics laboratories radioactive atoms are used as signposts to lead the way into the mysteries of the gene. That is, into the mysteries of life itself.

basic research and spin-offs

None of these uses, nor a hundred thousand others, were foreseen by the lonely investigators who first probed the secrets of the atom. It is always that way. But practical results–some people call them spin-offs (unexpected practical benefits)–always seem to happen when basic scientific research is successful.

fusion in the stellar furnace and forge

It may be that the most important spin-offs of all from nuclear research will be not in the power it gives us but in the wonder it excites, in the wisdom it provides. For it seems clear now that the secrets of creation may live inside that mysterious atomic nucleus. We do know that deep within stars like our sun, there is a nuclear furnace and forge. We know that in that furnace protons, electrons, quarks, mesons and all the improbable particles and fragments of particles we are just beginning now to discover are fused into the elements that make up our earth. (This is the same

nuclear fusion we are now trying to duplicate in our scientific laboratories on earth.)

stardust to atoms to earth

When stars explode with power beyond anything we can imagine on earth, they scatter atoms throughout space. On some fortunate place like our own planet, a local combination of these stardust atoms leads to interesting new possibilities.

the Big Bang recreated

Right now in places like Fermilab they have created machines powerful enough to imitate these stellar forces. As we speed atoms to energies like those at the center of stars, we are moving back in our experimental knowledge to within a few microseconds of what scientists think was the most energetic happening of all time–the Big Bang–the very beginning of the universe itself. What we will find there ... no one knows. Will it be useless "moonshine?"

We know that atoms make up all that exists, including you and me. Since all atoms on earth came from the explosion at the center of some long-ago star, this means that ...

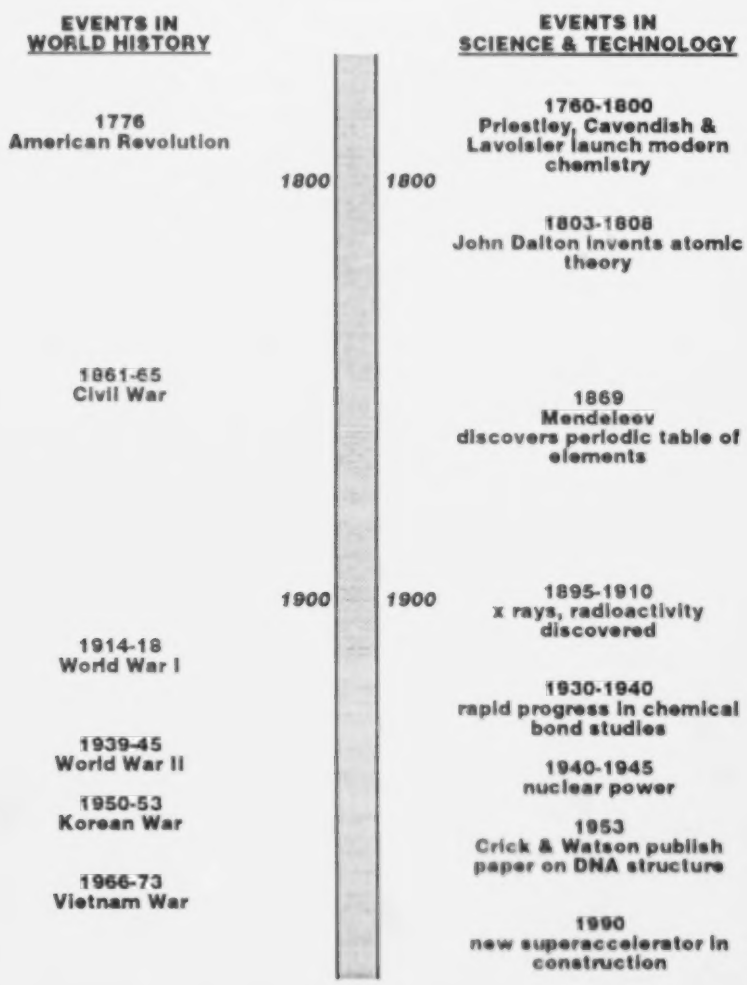
... we, too, are made of stardust!

a surprise

And even more surprising, we know it.

TIME ...

To understand the world of today it helps to know something about the world of yesterday. Kings and queens, wars and famines, presidents and paupers have all played a part. But more important than any of these in changing the past world into the world of today has been science and technology. The time line below will help you place important events and people in historical time.



SPACE ...

There is a saying, "If you don't know where you are going, any road will get you there." One of the important parts of knowing where you are going is a knowledge of geography. The map below will help you to locate the important events and people discussed in this book.

1. Cambridge, England — Cavendish Laboratory at Cambridge University, a world center for atomic research.

2. Paris, France — Lavoisier solved ancient mystery of fire here. Marie Curie, Henri Becquerel and others pioneered study of the atom's nucleus.

3. Leningrad, USSR — Formerly St. Petersburg, Russia. Dmitri Mendeleev worked here to discover the periodic table of the elements.

4. Lake country of England — The home base of John Dalton, who taught elementary school and invented modern atomic theory.

5. Copenhagen, Denmark — Niels Bohr headed the famous Institute for Atomic Studies here.

6. Alamogordo, New Mexico — Where the first nuclear explosion happened on July 16, 1945.

7. Batavia, Illinois — Site of Fermilab, where one of the largest accelerators (atom smashers) in the world is in operation.

8. Chicago, Illinois — At 3:45 p.m. on December 2, 1942, the atomic age began when a team of physicists led by Enrico Fermi achieved the first self-sustaining nuclear fission reaction. It happened in the squash court under the University of Chicago football stadium.

9. Oak Ridge, Tennessee — Where the fissionable isotope of uranium, U-235, was first produced by the gaseous diffusion process for the world's first atomic bombs.

10. Waxahachie, Texas — Near Dallas and Fort Worth. Where the new superaccelerator is in construction.

SPIRIT ...

Time and space are meaningless without spirit. Spirit is the part in each of us that understands. The part that sees connections between words and things–connections that surprise and make sense. Study the key words, concepts and ideas below so that you can understand how time, space and spirit worked in the past–and are working today.

absolute zero — The coldest possible temperature, 273 degrees below zero centigrade, where all motion stops. (p. 15)

accelerator — A large machine that speeds up subatomic particles to close to the speed of light. Popularly called an "atom smasher." (p. 21-23)

alpha particle — Nucleus of a helium atom. Two protons and two neutrons. (p. 9-10)

atom — What the world is made of. The smallest unit of every element.

Big Bang — A theory as to how the universe began some fifteen billion years ago in one cosmic explosion. (p. 23)

Brownian movement — The movement of tiny dust particles under a microscope caused by unequal jostling of atoms and molecules. (p. 6)

carbon — An element with unusually rich bonding possibilities. All life is based on this richness. (p. 19)

DNA — Deoxyribonucleic acid. The molecule that carries genes, the codes of life and the carriers of heredity. (p. 19)

ecology — The modern science that studies living things in their environment. (p. 22)

electrons — Negatively charged particles in the atom. The basic particle in electricity and electronics. (p. 1, 8-9, 19-20)

elements	Basic chemical substances that make up all material things. Each element has a characteristic atom. (p. 4-7, 16-17)
fission	The breaking apart of an atomic nucleus. (p. 12-13, 16, 21-22)
fusion	The joining together of atomic nuclei to make a larger atomic nucleus. (p. 22)
genetics	The science of heredity. (p. 19, 22)
helium	The inert gas element with two protons and two electrons. (p. 17)
hydrogen	The simplest atom, number one on the periodic table, with one proton and one electron. (p. 3, 17)
isotopes	Varieties of the same atom with different numbers of neutrons in their nucleus. (p. 12)
molecule	Two or more atoms bonded together in a unit. (p. 15-17)
neutrons	Particles with no charge in the nucleus of atoms. (p. 11)
nuclear energy	The energy held in the nucleus of an atom.
nucleus	The hard, massive, positively-charged center of an atom. (p. 10-11, 15-17, 20-23)
oxygen	An element essential to all life. (p. 3-5)
periodic table of elements	The organized list of all the elements in order of their atomic numbers. (p. 6-7, 16-17)
protons	Positively charged particles in the nucleus of an atom. (p. 9-10, 15-16)
quarks	Theoretical particles that make up protons and neutrons in the nuclei of atoms. (p. 21)
radioisotopes	Isotopes of an element whose nuclei break apart spontaneously and give out particles and energy. (p. 8, 16, 22)
radium	A radioactive element. (p. 8)

spin-offs Unplanned for benefits from some scientific discovery. (p. 22)

uranium A radioactive element used in nuclear bombs and nuclear power plants. (p. 8, 12-13)

x rays Radiation that comes from atoms and penetrates living tissues. (p. 7)

In addition to the above, *The Atom* also teaches about other important people, places, things, and ideas. Often you can figure out the meaning of a new term by seeing how it is used in context. Make sure you know the meaning of the following words. For help, check the pages listed in this Learning Power Book, or if necessary, a dictionary or encyclopedia:

Avogadro's hypothesis (p. 6); **Becquerel, Henri** (p. 8); **Bohr, Niels** (p. 10-11); **Boyle's Law** (p. 6); **carbon dioxide** (p. 4); **carbon monoxide** (p. 4); **Cavendish, Henry** (p. 3); **Curie, Marie** (p. 8); **Dalton, John** (p. 4-5); **Democritus** (p. 1-2); **Fermi, Enrico** (p. 12); **fiber optics** (p. 20); **hemoglobin** (p. 19); **Hiroshima** (p. 13); **hypothesis** (p. 5); **Lavoisier, Antoine** (p. 3-4); **Mendeleev, Dmitri** (p. 6-7); **Nagasaki** (p. 13); **photovoltaic cells** (p. 20); **Priestley, Joseph** (p. 3); **quantum leaps** (p. 11); **radiation** (p. 16); **Roentgen, William** (p. 7); **Rutherford, Ernest** (p. 9-10); **silicon chips** (p. 18); **spectral lines** (p. 10); **Thomson, J. J.** (p. 8).

STUDY SUGGESTIONS ...

1. Democritus thought the atoms in his brain were some of the same atoms that had made up the brain of the poet Homer, and would in turn be a part of all the other brains–including yours–down the corridors of time. Look up Avogadro's number and see if you can demonstrate this mathematically.

2. Modern chemistry owes a great deal to the three men mentioned in the program as pioneers of the late eighteenth century–Joseph Priestley, Henry Cavendish, and Antoine Lavoisier. Any one of the three would make a fine subject for library research and report.

3. In the early twentieth century the entire budget for scientific equipment at the famous Cavendish Laboratory was only 250 pounds (less than a thousand dollars) a year! Compare and contrast with financial support for science in the 1930s and in the 1990s.

4. Discuss the difference between "artificial" and "natural" in light of the fact that all materials are made of atoms that continually recycle through the biosphere.

5. The scientist Loren Eisley once wrote that we are made of "dust and the light of a star." What do you think of this way of putting it? How would you put it?

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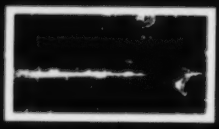

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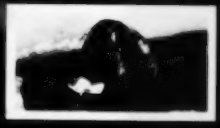

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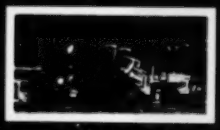

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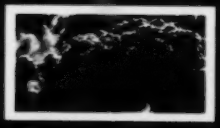

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